Aerosol-Cloud-Radiation Interactions in Atmospheric Forecast Models

John H. Seinfeld, Principal Investigator
California Institute of Technology
1200 E. California Blvd., M/C 210-41
Pasadena, CA 91125
(626) 395-4635; (626) 796-2591 seinfeld@its.caltech.edu

ONR Grant N00014-04-1-0118

LONG-TERM GOALS

The long-term goal of this project is to gain a deep understanding of the role of atmospheric aerosols in affecting transmission of radiation through the atmosphere and in influencing cloud properties.

OBJECTIVES

The scientific objectives of this project are to identify the specific manner in which atmospheric aerosols determine cloud properties and to represent these interactions in atmospheric models. The technological objectives are to develop state-of-the-art instruments for aircraft sampling of aerosols that advance the long-term goals of the project.

APPROACH

The main technical approach is to conduct aircraft studies of the atmosphere, in which comprehensive sampling of atmospheric particles and radiative and cloud properties is carried out. The aircraft studies are complemented by laboratory investigations and theoretical analysis. Key individuals participating in this work are Professors John H. Seinfeld and Richard C. Flagan at the California Institute of Technology and Dr. Haf Jonsson at Naval Postgraduate School. Professor Seinfeld serves as Principal Investigator. Professor Flagan plays a key role in instrumentation development and planning of aircraft

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE
Aerosol-Cloud-Radiation Interactions In Atmospheric Forecast Models

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
California Institute of Technology,1200 E. California Blvd., M/C 210-41,Pasadena,CA,91125

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long-term goal of this project is to gain a deep understanding of the role of atmospheric aerosols in affecting transmission of radiation through the atmosphere and in influencing cloud properties.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

operations. As Chief Scientist of CIRPAS, Dr. Jonsson oversees all aspects of aircraft measurements and data management.

WORK COMPLETED

The MASE-II field experiment was carried out in the eastern Pacific Ocean off Monterey, CA during July 2007 with the CIRPAS Twin Otter. Comprehensive measurements were made of aerosol and cloud properties in areas both perturbed and unperturbed by local emissions. Sixteen flights were made, with a total of 70 flight hours. We have analyzed data from 13 individual clouds, 5 of which have evidence of ship tracks.

RESULTS

A key hypothesized feedback resulting from an increase in cloud droplet number concentration owing to increased CCN concentration is an increase in cloud lifetime, thickness, and/or coverage resulting from precipitation suppression. The reduced sink of cloud water leads to a moistening and cooling of the MBL, lowering cloud base. If this were the sole response to precipitation suppression, then clouds would become thicker, adding to the increased cloud reflectance from reduced droplet size. Drizzle cools and stabilizes the subcloud layer. Suppression of drizzle reduces its stabilizing effect, however, leading to increased turbulence in the MBL and to increased entrainment of warm, dry air aloft. When dry air overlies the inversion capping the cloud, increases in cloud drop number concentration tend to lead to decreased liquid water path because of enhanced entrainment drying. This drying and warming effect, in some cases, can cancel the moistening and cooling owing to precipitation suppression. Thus one must evaluate carefully the competing effects of changes in surface precipitation and entrainment resulting from an increase in cloud droplet number concentration.

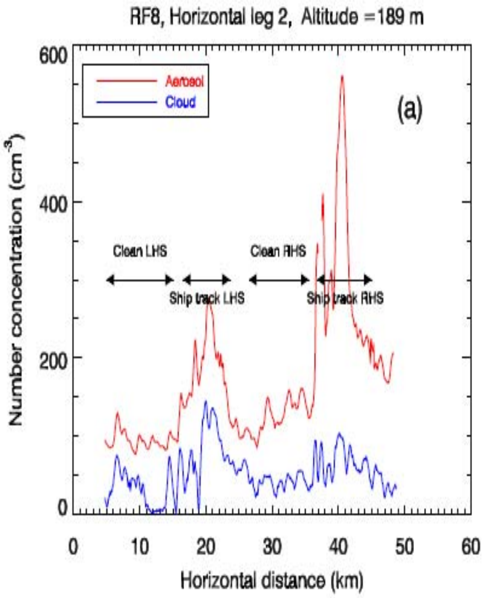
There are multiple effects on cloud thickness of a step change in cloud droplet number concentration, depending on the three key forcing variables that control the equilibrium structure of the MBL: (a) tropospheric divergence (which determines the vertical profile of the subsidence rate); (b) sea surface temperature (which controls the stability of the lower troposphere); and (c) free troposphere water vapor mixing ratio (which controls the ability of entrainment to dry and warm the MBL). One can define a ratio, R, as $\partial \ln h / \partial \ln N_d$. The sign and magnitude of this ratio are determined by the degree to which the entrainment cloud thinning/deepening is offset or enhanced by the precipitation suppression thickening. If the mixed layer is allowed to come to equilibrium after the perturbation in

N_d, the cloud always thickens. The timescale required to reach this equilibrium, however may be several days. On the timescales of interest (~ 1 day), the cloud top height does not have time to fully equilibrate, and R is strongly related to the initial cloud base height. Remarkably, for initial cloud base heights exceeding 400 m, R becomes negative, and complete cancellation of an albedo enhancement (R = -1) occurs for initial base heights of 600 to 700 m. Only when cloud base height is low (<100 m), does an albedo enhancement occur. Results are sensitive to the assumed drizzle drop mean radius. As the efficiency of entrainment weakens, weaker entrainment leads to a lower cloud base and less evaporation of drizzle in the subcloud layer. Larger initial cloud drop number concentration leads to weaker cloud thickness feedback (both positive and negative), but results are insensitive to the magnitude of the perturbation. Physically, an elevated cloud base permits more precipitation evaporation before it reaches the surface. This has two effects: (a) greater evaporation limits the moistening/cooling of the MBL that occurs when precipitation is suppressed, while allowing the suppressed precipitation to increase the entrainment drying/warming; and (b) greater sub-cloud evaporation exerts a stronger effect on the convective velocity scale w_* than in-cloud latent heating. On timescales of less than a day, feedbacks involving radiation and surface turbulent fluxes are relatively unimportant. In the subtropical MBL, although precipitation is very important, the amount of precipitation reaching the surface is low, and the MBL moisture budget is determined largely by a balance between surface evaporation and entrainment drying.

With these considerations in mind, the Marine Stratus/Stratocumulus Experiment (MASE-II) was carried out in July 2007 over the eastern Pacific near Monterey, California. Observational data on aerosol-cloud-drizzle relationships in marine stratocumulus have been analyzed during this year, carried out in regions of essentially uniform meteorology with localized aerosol enhancements due to ship exhaust (“ship tracks”). The data demonstrate, in accord with those from other field campaigns, that increased cloud drop number concentration N_c and decreased cloud-top effective radius r_e are associated with increased sub-cloud aerosol concentration. Modulation of drizzle by variations in aerosol levels is clearly evident. Variations of cloud-base drizzle rate R_{cb} are found to be consistent with the proportionality, $R_{cb} \propto H^3/N_c$, where H is cloud depth. Simultaneous aircraft and A-Train satellite observations have been used to quantify the precipitation susceptibility of clouds to aerosol perturbations in the eastern Pacific region.

REFERENCES

Lu, M-L., A. Sorooshian, H.H. Jonsson, G. Feingold, R.C. Flagan, and J.H. Seinfeld, “Marine Stratocumulus Aerosol-Cloud Relationships in the MASE-II Experiment: Precipitation Susceptibility in Eastern Pacific Stratocumulus,” *J. Geophys. Res.*, (submitted for publication).



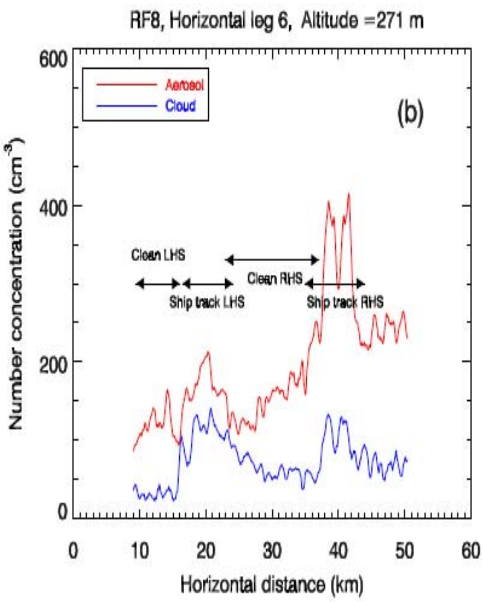


Figure 1. (a) Aerosol and (b) Cloud droplet number concentrations sampled on July 22, 2007 (Research Flight 8) during the MASE-II campaign. Cloud droplet (blue) and aerosol number concentrations (red) from two horizontal flight legs in RF8_1: (a) a leg in the lower (leg 2, altitude = 189 m) and (b) middle (leg 6, altitude = 271 m) portion of the cloud. From the spatial features of aerosol number concentration, one is able to discern the two ship tracks and the relatively cleaner regions surrounding them (see arrows). Data are smoothed in the forward direction in 10 s intervals.

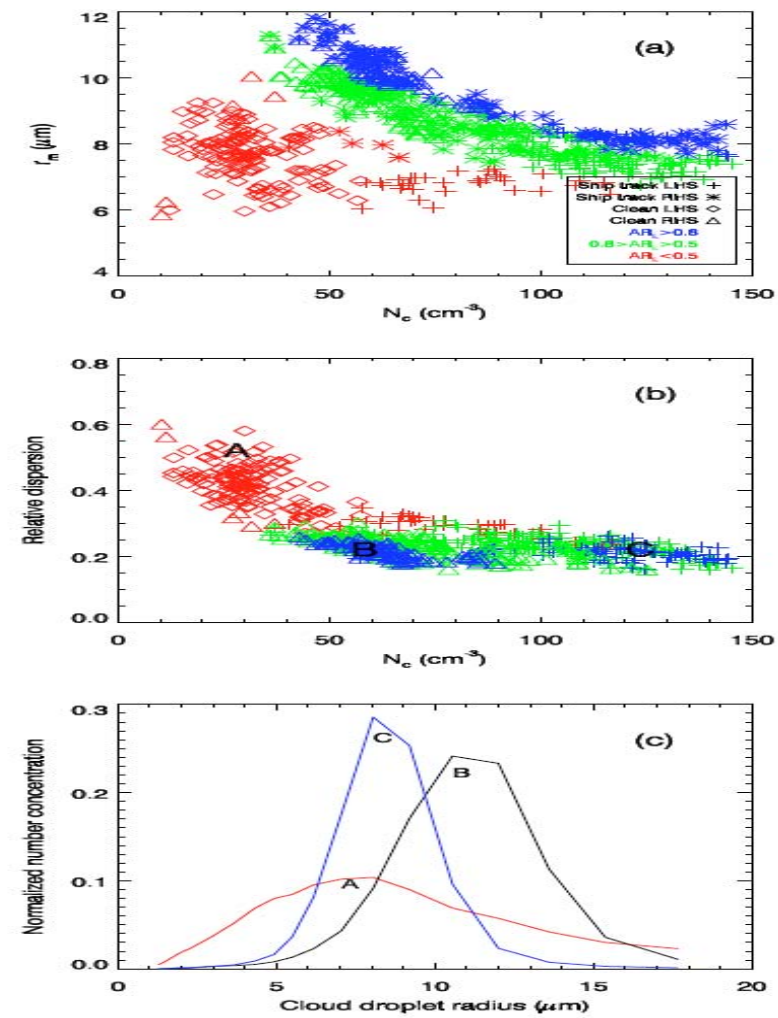


Figure 2. (a) Relationship between cloud droplet mean radius and cloud droplet number concentration and (b) relationship between relative dispersion and cloud droplet number concentration in RF8_1 for leg 6, altitude = 271 m. In the figure, data from the ship-track region and the clean regions, as identified in Figure 1, are represented by different symbols. The data are sorted according to the extent to which the cloud droplet number concentration profile is adiabatic: quasi-adiabatic ratio, $AR_L \geq 0.8$ (blue); moderately diluted, $0.8 > AR_L \geq 0.5$ (green); and strongly diluted, $AR_L < 0.5$ (red). (c) Cloud droplet number concentration normalized by its total number as a function of cloud droplet radius. The red line ("A") is the averaged size distribution for large dispersion ($d \geq 0.4$ and $N_c \leq 40$ cm^{-3}) data seen in (b). The blue line ("C") corresponds to small dispersion ($d \leq 0.25$, $N_c \geq 100$ cm^{-3}, and $AR_L \geq 0.8$). The black line ("B", $d \leq 0.25$, 60 cm^{-3} $\geq N_c \geq 50$ cm^{-3}, and $AR_L \geq 0.8$) serves as the middle case between "A" and "C".